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SEPTUM FEED OPTIMIZATION FOR PARABOLIC DISHES WITH FOCAL DISTANCE f/D IN THE RANGE OF 0.4.

THE PURPOSE OF THIS LECTURE IS TO DO A COMPARISON BETWEEN THE MEASURED PERFORMANCE OF A SEPTUM FEED WITH A PROPERLY DESIGNED HORN FLARE ADAPTOR, AGAINST THE SAME FEED ALONE, AND WITH A CHOKE- RING.

PART I – DESIGN & CALCULATION.

For the simplicity of its design and performance the septum polarizer feed is one of the best options available for illuminating a dish with an f/D of around 0.4. But with such f/D the dish has a total subtended aperture angle of about 130 deg., while a typical septum feed with choke-ring has a total beam-width at – 10 dB of about 144 deg. on the E and H plane, and 160 deg. at a 45 deg. pattern cut (Ref. 1), so that the main lobe itself is generating a good amount of spillover towards the ground, in addition to the spillover generated by side and back lobes, with an equivalent noise temperature of 25 deg. K in the best case, and comparable to the one produced by a good LNA for 1296 MHz (VK3UM EME Calculator).

By considering that spillover to the ground is usually the main contributor to the antenna noise temperature, to get an increase in the system's G/T I have decided to test a Flared Horn, as an adaptor, to be combined with a square septum polarizer with the purpose of shaping the main lobe to attain a total av. nominal beam-width of 120 deg. at – 10 dB. Flared horns have a complex behavior, so that their physical dimensions must be carefully selected. They may be adjusted to the desired f/D by varying the horn aperture size. Design data has been derived from classic textbooks and other papers in the References.

A dimensional cut of this Horn Adaptor is shown in Fig. 1. Practical waveguides have an aperture d larger than the operating half wavelength, and less than 1 wavelength to suppress higher order modes, so that the flare aperture of the horn should be less than 1 lambda to prevent the generation of higher order modes. If the flare angle is small enough, the higher mode field components are also small enough when compared with the dominant mode. Large flare angles show loss in gain, broadening of the radiation pattern and an increase of sidelobe levels in the 45 deg. pattern cuts (Ref. 2). A small flare half angle of 10 deg. has been chosen to provide a soft transition from the septum waveguide to the free space, by following the guidelines in Ref. 3.

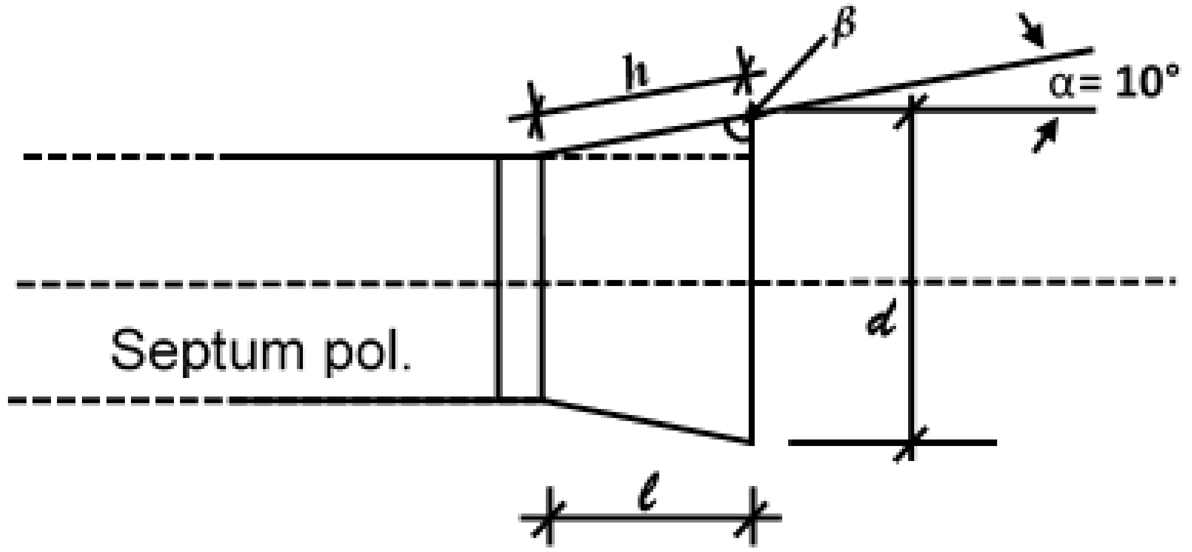


Fig. 1

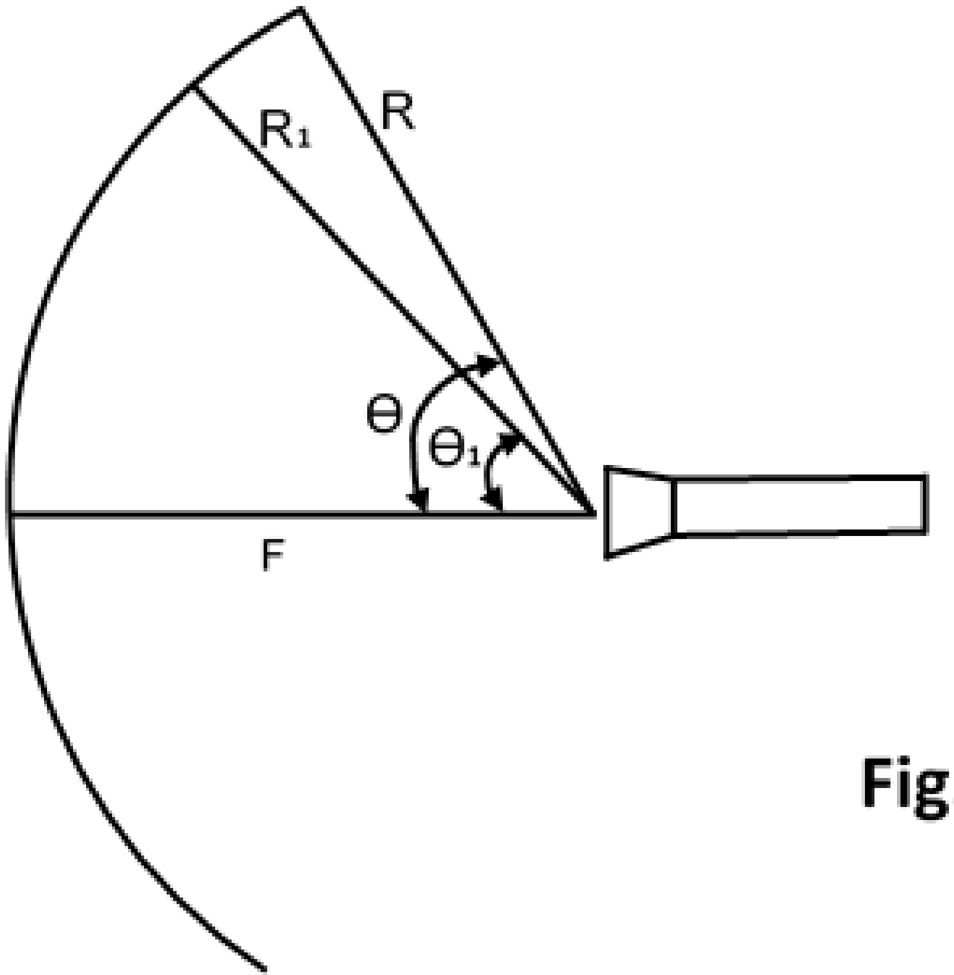


Fig. 2

•To verify that the formula given by A.W. Love (Ref. 2) will closely match the values of ½ beam-width measured on a septum polarizer with a square aperture of 150 x 150 mm.:

•Beam-width at -10 dB = (101 x Lambda) / d = 101 x 0.231/0.150 = 155.54 deg.

•½ Beam-width = 77.77 deg. (av. measured values: 72 deg. on the E and H plane, 80 deg. at a 45 deg. cut).

•To get a nominal av. value for ½ beam-width B of 60 deg. at – 10 dB when illuminating a dish with f/D = 0.4, and a subtended aperture angle of 130 deg.:

•d = 101 Lambda / 2B = 101 x 0.231 / 120 = 194 mm. (horn aperture).

•In this case we are intentionally under-illuminating the last 5 deg. sector at the dish edge by considering its lower contribution to the dish gain vs. spillover, due to the 1/ R^2 taper (Ref. 4).

•The ½ beam-width of 60 deg. at -10 dB has been chosen to put the beam-width 12 dB down at the edge of the dish for good side-lobe performance at the expenses of a small reduction in gain:

If, as in Fig. 2:

θ = 65 deg. = ½ subtended aperture angle of the dish at - X dB

$\theta_1 =$ 60 deg. = ½ subtended aperture angle of the dish at – 10 dB

•Since the beam ratio is proportional to the square root of the dB ratio (Ref. 5):

$\theta/\theta_1 = \sqrt{XdB/10}$; -X dB = 10 $(\frac{\theta}{\theta_1})^2$ = -11.73 dB

•By giving a half flare angle α of 10 deg. to provide a soft transition from the septum waveguide to the free space, and to limit the side lobes in the 45 deg. pattern cuts:

β = 80 deg. ; cos. β= 22 / h ; 0.173 = 22 / h ; h = 127 mm.

sin β= l / h ; 0.984 = l / 127 ; l = 125 mm. ; d = 2 x 127 cos β + 150 = 194 mm.

As you can see, physical dimensions are related to the dish f/D and size of the septum polarizer aperture, so that my calculation is valid for an f/D of around 0.4, and for a septum waveguide with an aperture of 150 x 150 mm.

When testing this flared horn on my 5 m. dish, to be combined with a square septum polarizer with an aperture of 150 x 150 mm., it has been showing about the same or better performance of a choke-ring, with an additional sensible reduction in spillover, clean main beam pattern with the 1st sidelobes dawn at -18 dB over a Sy normalized linear plot, same or better Sy readings, and by offering a minimum feed blockage on small dishes. This Flared Adaptor is also easy to build, with a low weight and wind resistance.

It has been made in one piece from a folded sheet of aluminum cal. # 20. A flange is providing the overlap to insert the Horn over the septum. The junction between the septum and the Horn has to be kept tight.

Despite its axial symmetry, the calculated beam-widths of this horn in the principal planes are unequal (Ref. 5). The symmetry could be improved by adjusting the height d of the flare aperture on the E or H plane, with perhaps an additional G/T improvement of a few tenths of a dB.

The field in the flare changes from a plane wave front to a curved one, which is desirable for feeding a parabolic dish (Ref. 2). The measured displacement of the phase center outside the horn aperture has been 35 mm., and it has to be taken into account when adjusting the feed focal distance.

PART II – MEASUREMENTS.

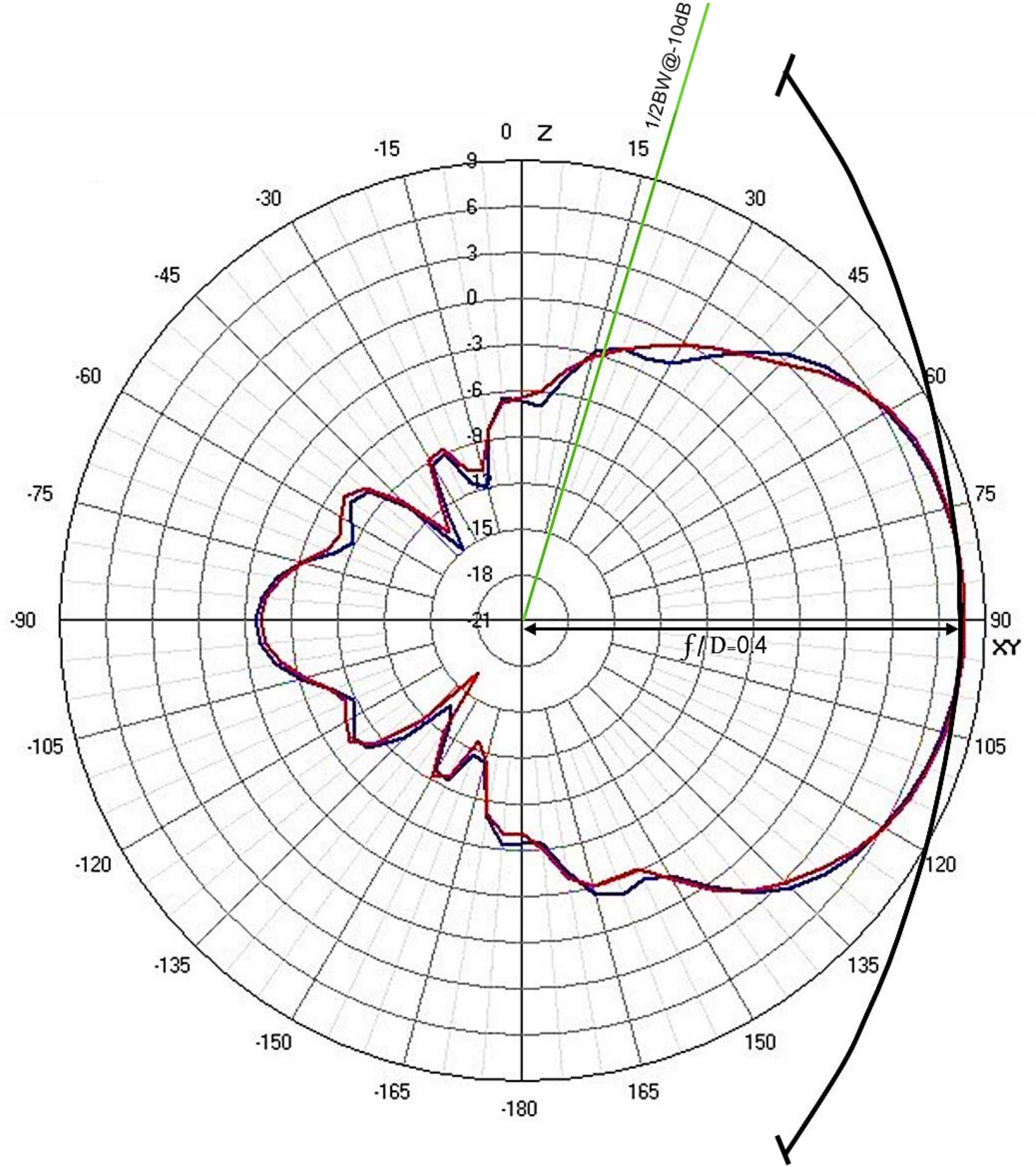
For a better understanding of why the OK1DFC Septum Polarizer has to be optimized for feeding a dish with an f/D around 0.4, we are going to see more details about this project.

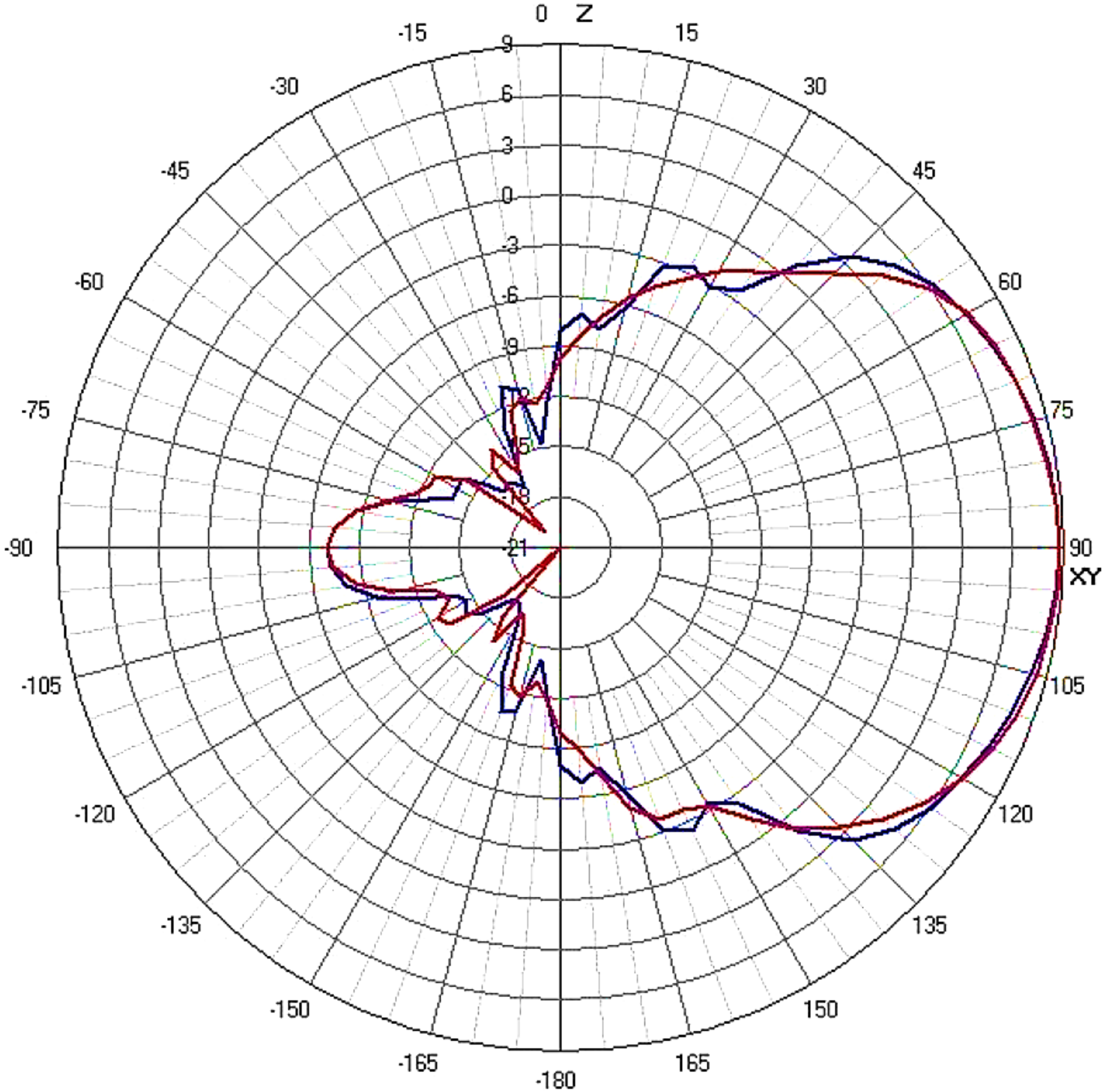
This is a 4NEC2 Simulated Polar Pattern of the OK1DFC bare Septum Feed Polarizer, located at the focal point of a parabolic dish with f/D = 0.4.

You will see that the Feed half Beam-width at – 10 dB is well out of the Dish subtended angle of 130 deg.

All the radiated energy above 65 deg. is Spillover.

OK 1 DFC SEPTUM FEED ALONE -
1/2BW@ -10dB=73 deg-
1/2BW@ 60°= - 9.0dB
1/2BW@ 65°= - 9.5dB





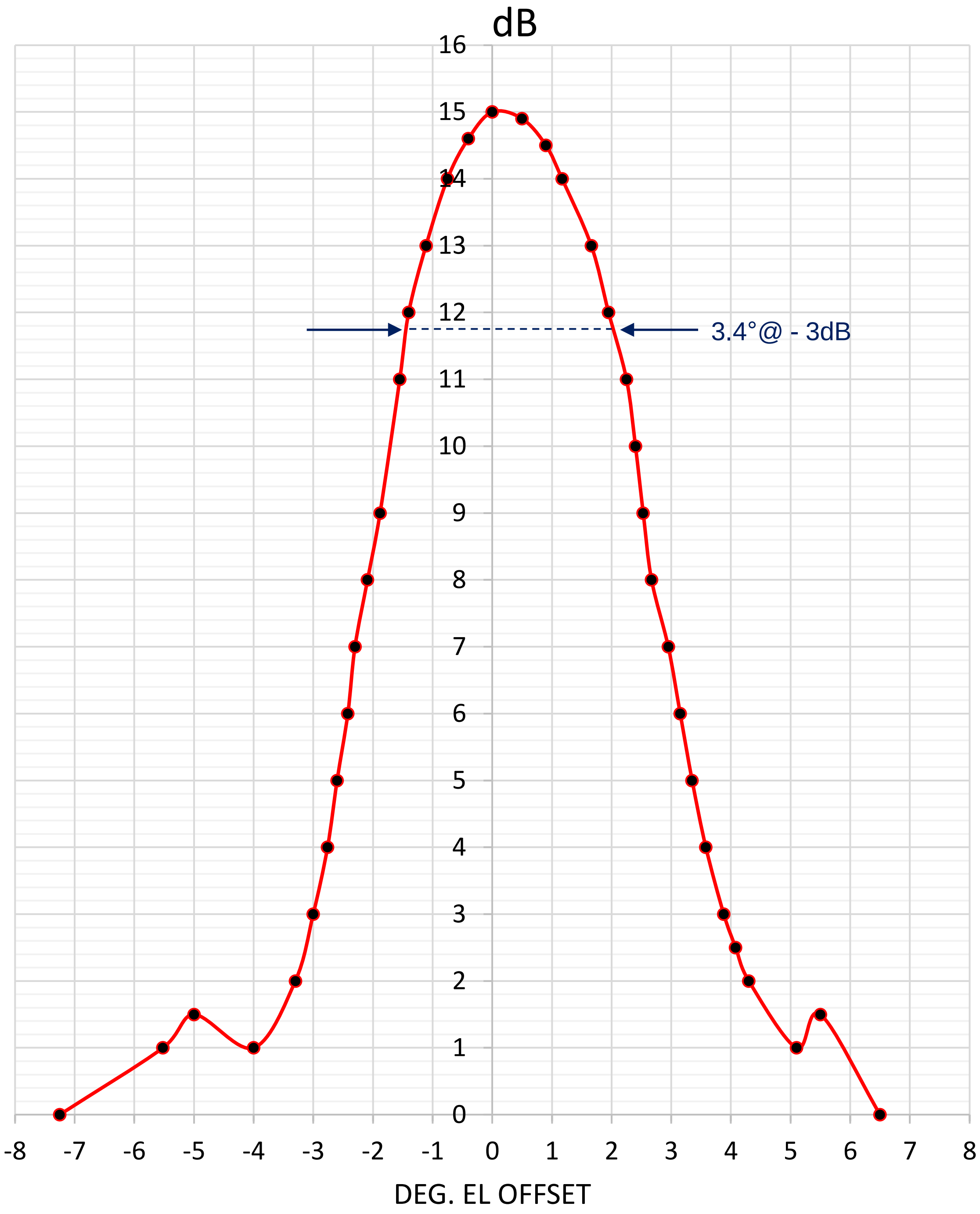
This is a Simulated Polar Plot of the OK1DFC Septum Polarizer with the Flared Horn Adaptor.

Results are pretty close to the calculated values.

OK1DFC SEPTUM FEED W/FLARED HORN ADAPTOR

½ BW@ -10dB= 53°-53°
½ BW@ 60°= -11.5, -12.0 dB
½ BW@ 65°= -12.0, -12.0 dB

You will see also a sensible reduction in the rear and back lobes.



MEASURING THE 1^{ST} SIDE LOBES LEVEL ON A NORMALIZED SUN LINEAR PLOT

A Sy linear plot of my 5 m. dish equipped with the Flared Septum Polarizer has been giving the pattern on attachment.

The plot is showing a clean main lobe with two “shoulders”, representing the 1^{ST} side lobes, at a level of 1.5 dB above the cold sky. You can’t see the deep nulls you would expect from plotting a traditional feed since the main lobe aperture at -3dB is abt, 3.4 deg. and the sun has an apparent angle of abt. 0.5 deg., by filling the gap.

It is possible to compute the normalized relative level of the sidelobes:

Y=(Sun + Cold Sky)/Cold Sky, then: Y-1=Sun/Cold Sky

Normalized level (dB) = 10 log (Y side lobes numeric - 1) / (Y sun numeric - 1)

Side lobes down at – 18.87 dB

(manual plotting has been giving an error of 0.16 deg. at the ½ power point)

The next step now is to find the best relationship between G/T Ratio and System Temperature:

When the Beam-width of the Feed is adjusted to properly illuminate the Dish what we are doing is to optimize our system's G/T Ratio, or Figure of Merit.

When the Beam-width is further reduced the G/T Ratio will drop below its max. value.

$$\frac{G}{T} = 8\pi K(Sy-1)/f(\lambda)^2 \qquad (1)$$

It will be easier to visualize the weight of the involved parameters if, for a set value of Solar Flux f, we call:

(8 π K) / f (λ^2) $a\ constant\ Factor\ C$. Then:

G/T = C (Sy – 1), where G is: η* G, and T is the System equivalent Noise Temperature (Tsys).

So that Sy is directly proportional to Dish effective Gain, and: Tsys is inversely proportional.

Then we have another Y Factor derived from the measured: GROUND to COLD SKY Ratio:

$$Y = \frac{Tant+Trx+Tgnd}{Tant+Trx+Tsky} \qquad (2)$$

Where: Tsys = Tant + Trx.

By under- illuminating the Dish, the Y Factor will increase, but the Dish Efficiency will decrease.

There are two indicators telling you when you will reach the max. G/T (break-even point):

- When the 1st Side Lobes are down at – 18 dB you will lose just abt. 1.0 dB of Gain (Edge illumination taper).
- When you reach a measured Y value with no further increase in Sy.

$Max.\ Sy\ means\ Max\ G/T\ Ratio\ and\ Max.\ Echo\ signal\ strength$. Optimizing the Beam-width of a feed for an f/D of 0.3 to fit a dish with an f/D of 0.4 with the proposed Flared Horn Adaptor makes a difference.

By testing an experimental feed that is not listed on the VK3UM Calculator you could now be able to calculate the involved parameters and compare results. For example, with the listed set values:

Ground to Cold Sky Y Ratio: 6.25 dB (Y Factor = 4.216).
Sy measured value = 15.0 dB (Sy Factor = 31.622).
Trx = Receiver eq. Noise Temp. = 18 deg. K (LNA n/f = 0.26 dB – 36dBG).
C = Constant Factor = 1.444 for a set Solar Flux f = 45 Watts/m^2/Hz at $\lambda_{0.}$, (Measured on quiet Sun)
Tsky = 10 deg. K. ; Tgnd = 290 deg. K.

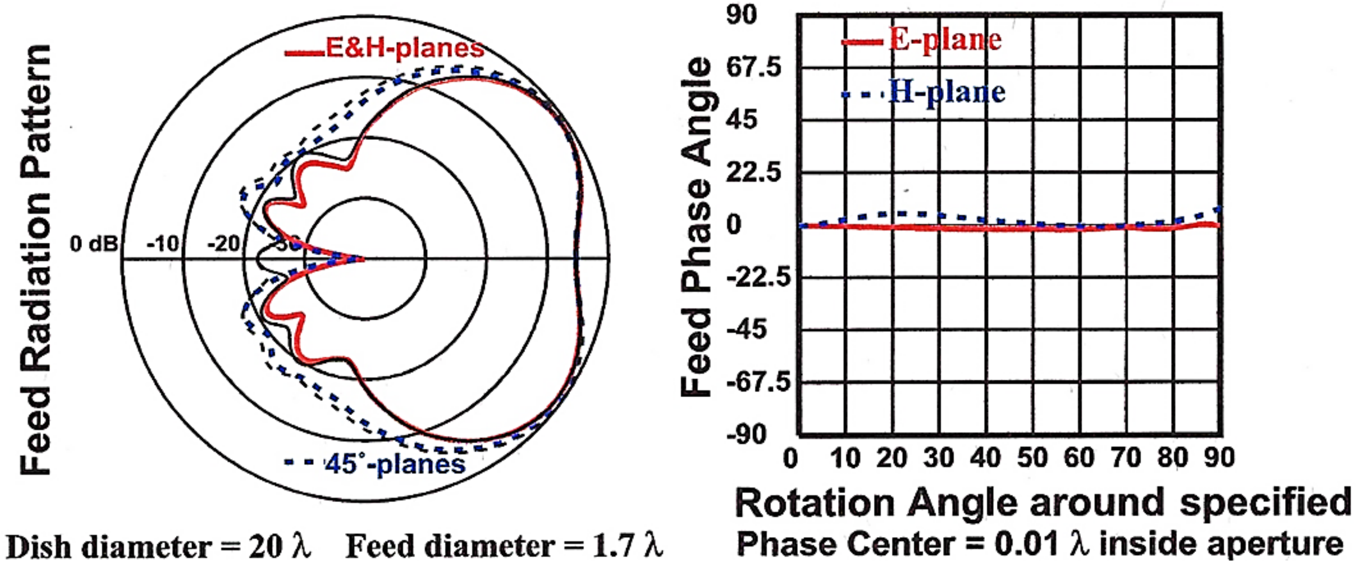
By solving (2) for Tant = $\frac{(Tgnd+Trx)-Y(Tsky+Trx)}{Y-1}$ = 59 deg. K. (Add comments about additional losses).

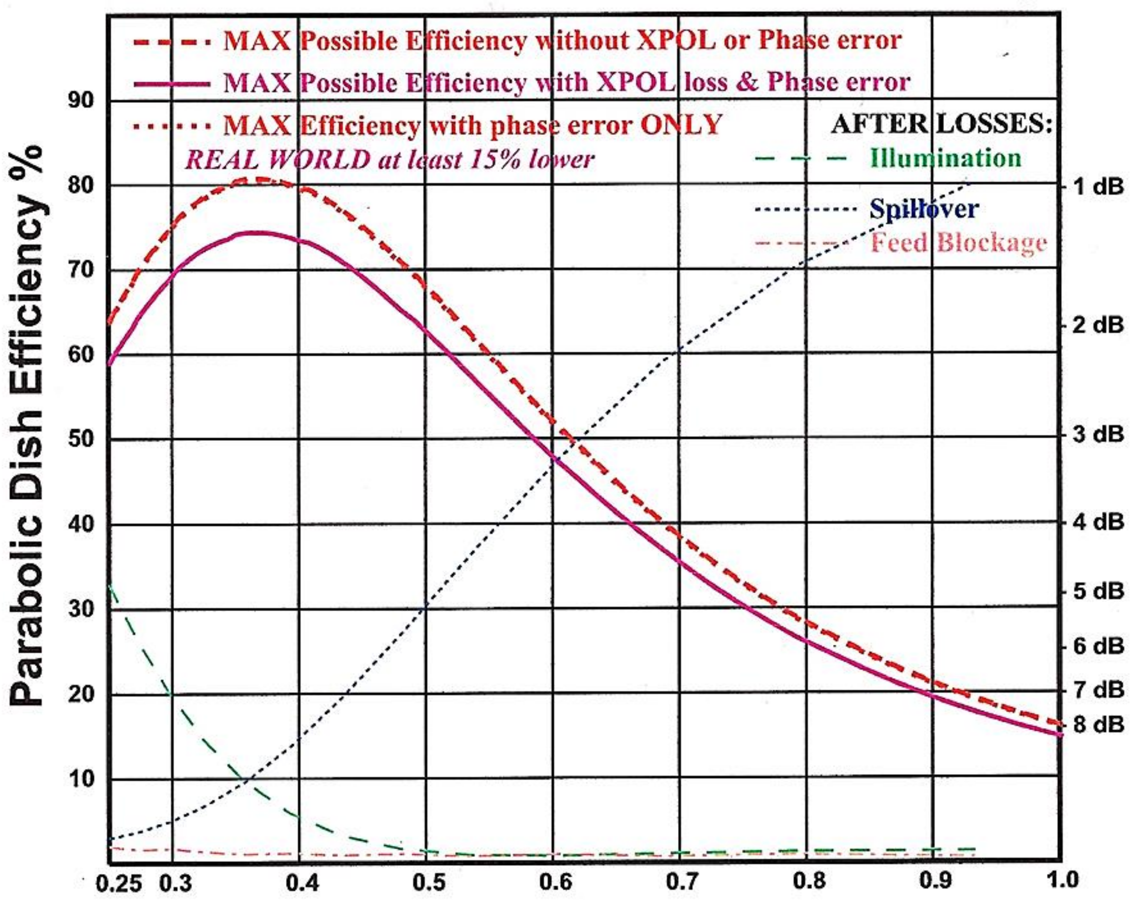
Tsys = Tant + Trx = 59 + 18 = 77 deg. K.
As we have seen before: G/Tsys = C (Sy -1),
G = C Tsys (Sy – 1) = 3,405 (35.32 dBi). Since G is: $\eta(\pi D/\lambda)^2$:
For a 5 m. Dish: G = η * 4,624.
η (Efficiency) = (3,405 / 4,624) * 100 = 73.6%.

Different methods of calculation make a difference in the resulting Tsys value and Dish-Feed Efficiency. The VK3UM Calculator is considering: Tsys = Tspill + Trx + Tft + Tsky, but into Tant there are other factors, like:

scattering and reflections from feed and supports, edge diffraction from the dish rim, aperture blockage and dish surface losses, that should not be underestimated.

Figure 13 - Square septum feed with choke ring
Ring 2.0λ dia x 0.375λ deep, back 0.175λ, RHCP





For a choke ring Feed design, courtesy of W1GHZ (Ref. 1)., you will see that in the “real world” the dish efficiency is reaching a value of abt. 74%, that probably looks more realistic than the calculated value of 80.4% derived from the VK3UM Calculator.

According to Henry Jasik (Ref.5), the best mathematical work predicts a max. Dish-feed efficiency of 74%, therefore we must be satisfied to be able to get such values.

When the Horn's Flare is properly designed for a set f/D ratio, by putting the 1st sidelobes down between -18 and -19 dB, you will reach the max. G/Tsys ratio; that means the max. signal strenght of your own echo and the best receiving performance for your system, with a minimum feed blockage.

Additional comments about Septum Feed Optimization and calculated efficiency:

Measuring the Sy of your system on 23 cm. is a quite easy task if you are located ouside of an urban area with a very low level of man made noise when measuring Tcs.

Measuring the Tgng/Tcs Y ratio is requiring more attention, since the formula (2) that is giving the Antenna Temperature: Tant, is very sensitive to a small variation of this Y ratio.
If you get Tgnd by pointing your dish toward the far field, you could be measuring a value below the real one, since the cold sky temp. is reflected by the ground.
If you get Tgnd by pointing your dish toward "trees in full leaf", please do not forget the comments we have seen on the HB9Q logger, as: I have the dish in the trees and I'm still copying you!. Trees are not always the best RF absorber. The best option to do such measurement is to put a thick MW foam absorber over the mouth of your feed.
Just as an example, if you are measuring Tgnd/Tsky ratio with an error of -10%, you will find an increase of 52% in the calculated Tant temperature, and an unrealistic value for your dish efficiency. Sy and Tgnd/Tcs are strictly related parameters that should be carefully measured, so that even the calculated efficiency for my system could present some margin of error.
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REFERENCES:

(1) Paul Wade - Enhancing the OK1DFC Square Septum Feed with a Choke Ring. www.w1ghz.org
(2) A.W. Love – Electromagnetic Horn Antennas. CH 14-7, 14-23.
(3) A 23 cm. Diagonal Waveguide Feed – Russ Miller,
(4) Technical Report #5 – The Crawford Hill VHF Club. Page 2.
(5) H. Jasik – Antenna Engineering Handbook. CH. 10.